Volunteer performance in urban forest survey initiatives

A THESIS SUBMITTED TO THE FACULTY OF
THE GRADUATE SCHOOL OF THE UNIVERSITY OF MINNESOTA
BY

Nicholas Bancks

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER

OF SCIENCE

Advisor: Gary Johnson

May 2017

Acknowledgments

I would like to first acknowledge my advisor, Professor Gary Johnson, who was incredibly patient, supportive, and flexible during my entire extended graduate term. His ability to hold me accountable, with grace, dignity, and a little humor was sincerely appreciated during this entire process. Thank you to Dr. Mae Davenport and Dr. Carissa Schively Slotterback for agreeing to serve on my committee. Also, thank you to Dr. Eric North, who once told me, “urban forestry is a tough game, with no money.” Your insights, commitment to this research, and patience during numerous meetings was invaluable.

I would like to thank the University of Minnesota’s Natural Resources Science and Management graduate program for selecting me as recipient NRSM Block Grant Fellowship. Also, thank you to the U.S. Forest Service, the Minnesota Department of Natural Resources, and the Minnesota Department of Agriculture for awarding the grant that supported the volunteer survey initiative and portions of my research activities. This financial support was vital in helping me to finish out necessary work that underpins this research.

Thank you to all the members of the university research and outreach team who helped collect data on over 800 trees across ten Minnesota communities. Research assistants included Lauren Stufft, Jeff Carroll, Dustin Ellis, and Casey Dubrowski.

Finally, I would to thank my family, especially my wife Jodi, who has been unwavering in her support of me ever since I went back for a graduate degree and started counting

and measuring trees. Your encouragement, support, and love helped to see me through this; I would not have been able to accomplish this without you.

Abstract

In 2010, the University of Minnesota Forest Resources Department implemented a community engagement program that drew upon community volunteers. This program sought to help greater Minnesota communities assess and mitigate the potential damages brought upon by the arrival of the invasive emerald ash borer. Volunteers were trained to survey their local urban forest, collecting information on species, size, age, and condition of the city trees as part of the process. A growing number of environmental monitoring programs and natural resource managers have begun to utilize and incorporate volunteer-collected data as part of their comprehensive management strategies. Volunteer-driven programs can help to enhance community capacity and participation in future municipal resource management challenges while providing cost-effective alternatives for local municipalities. However, little information exists regarding the real and perceived accuracy of volunteers undertaking urban forest survey initiatives. An evaluation of nine community tree surveys and two training protocols has provided assessment of volunteer accuracy regarding tree survey data collection.

Table of Contents

List of Tables

List of Figures

Introduction

Brief history of urban forestry

Urban forestry in the United States as a conceptual definition was first fully articulated in 1970 (Jorgensen, 1986) as a specialized division of forestry that sought to manage and grow trees for the multiple benefits they provide to urban society. As a professional institution, urban forestry's origins in the United States reach back as far as the late 19^{th} century (Kinney, 1972; Ricard, 2005; Konijnendijk et al., 2006), however, the modern concept of urban forestry as it relates to provision of societal benefits for city dwellers has origins in Europe that date back hundreds of years to the Middle Ages where local militia groups protected the Eilenreide forest from illegal uses on behalf of the citizens of the city of Hannover, which was near the forest (Konijnendijk, 1997).

Urban forests have long been recognized for the benefits they provide. The importance of greenspace planning and management gained prominence throughout Europe during the wave of massive industrialization that swept the continent during the 19^{th} century. Public greenspaces, such as urban parks and gardens, were recognized as significant contributors to the quality of life and health for the large population of working class city dwellers (Konijnendijk et al., 2006). Though urban forest management was valued and practiced at municipal level in parts of the United States prominently since the late 19^{th} century, two major legislative actions contributed significantly to a national expansion of urban forestry within the United States. Both the passage of the federal Cooperative Forestry Act of 1978 in the United States, and the subsequent involvement in urban forestry by the US Forest Service (Robbins, 1985), and the 1990 Farm Bill, which created the Urban and Cooperative Forestry Program and National Urban and Community Forestry Advisory Council whose purpose was to create policy to guide the preservation and health of America's urban forests, were instrumental in laying the foundation for recognition of urban forestry as a fundamental component of green infrastructure. While traditional silviculture emphasized wood production urban forestry's primary importance was to manage urban forests for recreation, environmental protection, and ecological benefits (Miller, 1997).

Benefits of urban forests

A substantial benefit of urban forests is their ability to lock up and store large amounts of atmospheric carbon dioxide, a byproduct emission that comes mainly from the burning of fossil fuels, including natural gas, oil, or coal. Carbon dioxide is a primary greenhouse gas, contributing significantly to the warming of the planet by trapping heat within Earth's atmosphere. Past research has estimated urban forests in Chicago, Minneapolis, and Washington, D.C. store as much as 150,000 to 526,000 tons of carbon dioxide annually from the atmosphere, which was valued $4.6 million on a yearly basis in Minneapolis, and as high as $9.7 million in Washington, D.C. (Nowak, 1994; Nowak et al., 2006); similarly, researchers found the urban forest in Beijing, China reduced carbon emissions by approximately 200,000 tons annually (Yang et al., 2005). In the United States total carbon storage by all urban forests is estimated to reach 990 million tons annually (McPherson et al., 1994). A residual benefit from the sequestration of carbon by urban forests is realized in reduction of future carbon emissions which are avoided annually due to energy conservation. This reduction is as high as 12,600 tons annually in cities like Chicago (Nowak, 1994).

Reduction in heating and cooling costs are another benefit associated with the urban forest. The presence of shade tree trees can have a significant influence on the mechanical thermoregulation of residences and commercial buildings within a city. In some instances, the savings in heating and cooling costs was estimated to be between $50 and $90 annually per household, or 10 percent of a typical heating and cooling bill in Chicago (McPherson, 1994), whereas other studies have shown yearly energy saving can reach as much as $1.57 million on a city-wide basis (Brack, 2002). Urban forests can have a particularly dramatic effect on cooling costs. Tree impacts on cooling costs within Sacramento County, California saved an estimated $18.5 million, or 12% of the annual expenditure on cooling costs for residents and businesses within the county (Simpson, 1998).

Urban forests also play a vital role in filtering out large particulate matter and other pollutants from the air. Modeling has estimated that city trees remove 1,261 tons of pollutants from the air on an annual basis in Beijing (Yang et al., 2005), whereas Nowak et al. have found the urban forest in Minneapolis removes as much as 384 tons of air pollution per year, at an annual savings of almost $2 million (2006). For areas of high metropolitan population density potential reduction of air pollution can be quite significant. Estimated benefits due to smog reduction by trees in the Los Angeles basin amounted to an annual savings of $180 million (Rosenfeld et al., 1998).

Precipitation inception by urban forests and the subsequent reduction in stormwater flow helps cities in the amelioration of flooding and management costs. In Bismark, ND, an average large city street tree intercepted 2,985 gallons of precipitation annually, accounting for an estimated 51% reduction in stormwater runoff, amounting to almost $500,000 in yearly cost benefits (McPherson et al., 2005), whereas analysis of tree cover in the metropolitan area of Washington, D.C. was estimated to have reduced stormwater storage costs by as much as $4.7 billion (Wolf, 2004). A similar study in California limited to just the city street and park trees of Santa Monica estimated the annual benefits attributed to avoided stormwater treatment and flood control costs to be as high as $110, 890 for the city (Xiao & McPherson, 2002).

Other benefits of urban forests accrued by cities and their residents include increases in property values, reaching as high as $2.5 million on an annual basis for Berkeley, CA (McPherson, 2005). Research indicated property owners pay premiums to live in neighborhoods with greener, and more dense vegetation as evidenced by appraised property values of homes that are adjacent to parks and open spaces (Wolf, 2004; Payton et al., 2008). Similar studies on the economic impact of city street trees have shown consumers tend to spend on average approximately 12% more on goods and services in cities where downtowns incorporate trees as part of city infrastructure compared to downtowns where trees are largely absent (Wolf, 2004). Mental health benefits are often attributed to urban forests as well. Residents in an inner-city, low-income, high crime neighborhood of Chicago felt a greater sense of security, had stronger social bonds with neighbors, experienced less crime, and spent more time outside engaging with one another if there was a presence of trees and maintained greenspace, as opposed to residential spaces absent of any vegetation and seemed uninviting (Kuo, 2003). Similarly, Kaplan found urban places where nature is a key component of the space to have profound psychological benefits, including increased satisfaction and self-worth, for residents who live in these areas (2004).

Cost and capacity concerns

The management and stewardship of urban forests, the costs these activities incur, and the issues concerning capacity necessary to implement adequate maintenance are sources of concern and contention for resource managers across many cities in the U.S. Generally, the source of annual costs for maintaining and sustaining urban forests lies primarily with planting, maintenance and administrative activities associated with urban forest management (McPherson et al., 2005; Nowak & Dwyer, 2007). However, there are also costs due to damage caused to infrastructure (sidewalks) by tree roots, or property by falling tree branches (Dwyer, 1995). A study of five different cities across the Midwest and Western U.S. indicated pruning and inspection costs far outweighed costs associated with the initial planting of city trees (McPherson et al., 2005). While the upfront costs of maintaining city trees are well known, the resultant costs of deferred management activities are not as apparent in the literature, nor as readily understood by resource managers or decision makers (Vogt, Hauer, & Fischer, 2015). A review of the literature by Vogt, Hauer, and Fischer (2015) also found some specific maintenance actions, when deferred, carry significantly greater costs to the urban forest than others. These activities included caring for trees early on during their establishment, actively managing for diseases and pests, or replanting trees to sustain the resulting net benefits gained by healthy and robust urban forests.

Effective urban forest management is dependent on the ability to develop, implement, and sustain the activities necessary for realizing the benefits of the urban forest. Utilizing capacity is linked to the provision of technical and financial resources. Hauer and Johnson (2008) noted that increased federal funding for urban and community forestry coincided with increased technical support at the state level, directly impacting planning processes, such as strategic plan development, which provide a pathway to meet goals and achieve necessary resources. However, quite often products of the planning process, such as management plans, lack the necessary specificity to implement meaningful and effective stewardship of the urban forest. A study of the comprehensiveness of urban forest management plans in Washington State found the overwhelming majority of plans lacked detailed action steps as part of an implementation plan, indicators of success for monitoring, consideration of budgetary implications, or even a timeline for implementation (Gibbons & Ryan, 2015).

Beyond provision of technical and financial resources, recruitment and engagement of members within the communities directly benefits management of the forest resource. Community members, groups, and organizations become actively involved with the stewardship of their urban forest when they can make meaningful connections with their mission to the management of urban forest and acknowledge the shared responsibility of both public and private interests in resource management (Elmendorf et al., 2003; Jack-Scott et al., 2013). Drawing upon community members can support and increase the ability of municipalities to plan and implement activities that maintain and sustain their urban forests.

Use of volunteers in natural resource management

The use of volunteers to aid in monitoring, maintenance, and stewardship is prolific across the profession of natural resources management. In particular, water quality monitoring has benefited from the use of volunteers, or "citizen scientists". Government agency programs in Minnesota, North Carolina, Ohio, Connecticut, Virginia, and Washington utilized large volunteer networks to assess and track water quality trends in lakes, rivers, and streams (Heiskary et al., 1994; Penrose & Call, 1995; Fore et al., 2001; Engell & Voshell, 2002). Similar efforts drawing upon volunteers have been used to monitor for the presence of both aquatic and terrestrial invasive species as part of early detection and response initiatives across the U.S. (Brown et al., 2001; Brandon et al., 2003; Delaney et al., 2007; Crall et al., 2011). Other volunteer-reliant programs have focused upon increasingly complex tasks such as biodiversity assessment or species dynamics in ecosystems (Engell & Voshell, 2002; Foster-Smith & Evans, 2003; Leslie & Velez, 2004; Gillett et al., 2012). Within the profession of forestry, there are numerous examples of programs using volunteers to inventory, assess, and monitor forest systems at both a state and local level (Rock & Lauten, 1996; Brandon et al., 2003; Galloway et al., 2006; Crall et al., 2011). Though utilization of volunteers in resource management programming is a widely-accepted practice across the natural resources field it is not without controversy or skepticism.

Often, when volunteers collect data, or assess a resource, concerns about validity and accuracy of information are common. Any organized effort that seeks to gather information on the present state of a resource relies on data that is both accurate and useful. The degree of accuracy determines the relative usefulness of the data as an informational tool for resource management. Additional factors such as direct financial cost, investment of resources that detract from other areas of need, or time spent on task also influence management decisions, but considerable time and energy has been spent assessing the performance and accuracy of volunteers. Increasingly, evidence supports the notion that volunteers can collect data of similar quality to that of professional scientists (Penrose & Call, 1995; Rock & Lauten, 1996; McLaren & Cadman, 1999; Brown et al., 2001; Fore et al., 2001; Nicholson et al., 2002; Engel & Voshell, 2002; Delaney et al., 2007; Crall et al., 2011; Gillett et al., 2011).

The value of using volunteers in natural resource management also extends beyond the collection of large amounts of data otherwise not achievable by a few professional staff or contractors on the same spatial and temporal scales. In instances where students were utilized as part of the programming, real educational benefits, mentorship opportunities, and career exploration were provided (Rock & Lauten, 1996; Galloway et al., 2006). Other examples specific to community forestry programming effectively use volunteers to develop, promote and maintain healthy urban forests. These programs are predicated on educating and raising awareness of the participants regarding the importance of healthy community forests. Volunteers then put their knowledge to use by taking part in tree planting activities and maintenance (Makra & Andresen, 1990; Westphal, 1993).

Volunteers and urban forestry inventory initiatives

Despite the wealth of research concerning volunteer efforts in the broader field of natural resource management little evidence exists to support the use of volunteers in urban forest inventories and data collection. Most research is restricted to the natural forest environment, apart from any urban setting (Rock & Lauten, 1996; Brown et al., 2001; Brandon et al., 2003; Galloway et al., 2006; Crall et al., 2011). Bloniarz and Ryan's (1996) examination of volunteers in an urban forest inventory initiative across two communities of suburban Boston stands out as a seminal study of the efficacy and reliability of citizen science in an urban forestry context. More recently, efforts were made to assess the quality of data collected by volunteers as part of urban tree inventories in several cities across the upper Midwest, as well as Malmö, Sweden. In some instances, results were very encouraging, particularly in volunteer ability to identify trees at the genus level, and assessment of mortality status (Roman et al., 2017). However, volunteer assessment of other parameters, such as crown transparency, wood condition, or maintenance needs displayed lower levels of agreement with assessments of the same trees collected by professional scientists (Cazod, 2005; Roman et al., 2017). Further examination of volunteer accuracy and how it relates to the data collected from urban tree inventories, will help refine and improve the use of volunteers, as well as volunteer experience and engagement, to aid the management of urban and community forests.

Literature Review

Trained volunteers have long been utilized by natural resource managers as part of larger programmatic approaches to resource monitoring and management (Makra & Andresen, 1990; Heiskary et al., 1994; Penrose & Call, 1995; Rock & Lauten, 1996; Brown et al., 2001; Leslie et al., 2004; Topp-Jorgensen et al., 2005; Galloway et al., 2006). Increasingly in urban and community forestry, agencies and local governments are relying on volunteers to carry out programmatic goals and while utilizing volunteers can add much to a program, the mismanagement of this same resource can lead to problems (Ball, 1986). Historically, the validity and usefulness of volunteer-collected data for use in natural resource management has been a common concern and source of scrutiny. As governmental agencies increasingly look to volunteer-generated data to support monitoring and management programs the quality of data has been cited as a source of major concern among regulatory bodies and scientists (Penrose & Call, 1995). This is primarily attributable to a lack of understanding regarding the potential for error, or bias, of volunteer-collected data (Dickinson et al., 2010).

More recent research efforts have focused on both the accuracy of volunteer-collected data and effectiveness of natural resource management initiatives that utilize citizen science as part of a management portfolio. However, assessment methodologies for evaluating volunteer accuracy vary significantly across different sources. Analysis of water quality volunteer-collected data and professionally collected data for a specific parameter at a specific location by Nicholson et al. (2002) provided a direct comparison for assessment of volunteer accuracy. This one-to-one assessment of parameters was useful in examining variability across the volunteer and professional data sets but was vulnerable to selection bias and temporal differences in data collection. Other volunteer-collected water quality data studies (Mattson et al., 1994) were better able to control for selection bias by random selection of sampling sites for quality control, and by having scientists collect water samples at approximately the same time of the corresponding volunteer sample.

Study design and sampling protocol also influence accuracy of volunteer data. Volunteer-collected data characterizing coral reef habitat differed from scientist data due to selection bias towards more complex reef sections (Gillett et al., 2011), and student volunteers surveying white oak stands altered transect lines to capture unique tree species (Galloway et al., 2006). Assessment of the performance of volunteer stream monitoring in Washington found volunteer data and stream assessments comparable to data collected by professionals (Fore et al., 2001). Assessment of volunteer accuracy was also evaluated based upon direct comparison of volunteer collected data to that collected by professional following the same sampling protocols at the same sampling locations. Analysis of variance (ANOVA) modeling was utilized to examine for evidence of any significant statistical difference between the samples collected by volunteer and professionals (Fore et al., 2001).

In volunteer-based forest monitoring programs volunteers and the quality of their data has been assessed through a variety of methods and statistical tests. Volunteers and state botanists collected the same data parameters along transects in forest systems across Illinois. Comparison between volunteer and botanist data was analyzed using paired t-tests to detect statistical difference at the 0.05 significance level (Brandon et al., 2003).

Similar discrepancies in statistical significant levels of agreement between volunteer and professionally collected transect data were present in an assessment of several white oak stands in Oregon; both the Mann-Whitney test and chi-square goodness-of-fit test were used for methods of statistical comparison across the different parameters collected along the transect line (Galloway et al., 2006). Chi-square analysis of volunteer and professional comparison was also utilized in a study of invasive species monitoring protocol in Colorado and Wisconsin (Crall et al., 2011).

Adequacy of data is key distinction in how accuracy was distinguished during examination of volunteer-collected data. Mattson's efforts supported the belief that volunteers were reliably and accurately able to produce data that was adequate for purposes of detecting trends in environmental conditions (1994). Bloniarz and Ryan's seminal study of volunteer accuracy in urban forest inventories established both statistically significant and pragmatically-acceptable levels of agreement between volunteer-collected data and professional data (1996). Volunteer accuracy was examined utilizing both thresholds, with volunteer-collected data comparing favorably with the quality of the same professional assessment of each individual tree variable when considering practical levels of agreement. A similar differentiation between statistical significance and practical levels of agreement was posited in an analysis of volunteer accuracy in the Illinois *ForestWatch* program. Interestingly, results indicated high levels of statistical agreement for certain study parameters, but low levels of agreement from a practical standpoint for other forest health parameters (Brandon et al., 2003). Regardless, usefulness of data based upon the distinction between practicality and statistical significance is one important consideration when including community volunteers in the resource management process.

Differences in levels of agreement between data collected by volunteers and by professionals were often attributable to one, or a combination of several factors. Among these factors several, including volunteer age (Delaney et al., 2007), duration and complexity of task (Penrose & Call, 1995; Darwall & Dulvy, 1996; Brandon et al., 2003; Foster-Smith & Evans, 2003; Newman et al., 2003), and amount of training (Fitzpatrick et al., 2009), were generally common and reoccurring across the many studies that examined the reliability and accuracy of volunteer-collected data.

Complex and varied environments can affect accuracy of volunteer-collected data. Volunteers collecting information on marine organisms along the shorelines of Scotland struggled when confronted with heterogeneous environments that provided greater complexity and more difficulty in assessing species diversity (Foster-Smith & Evans, 2003). Intensive, detailed studies also present challenges to volunteer accuracy. Comparison of data quality collected by volunteers performing detailed coral studies in a single location to more generalized data collected by volunteers across multiple sites indicated decreased levels of accuracy (Darwall & Dulvy, 1996).

Volunteers were used as part of a monitoring program in Illinois to track the health and composition of forests across the state. Accuracy was evaluated based upon the volunteers' ability to collect data that would gauge forest age structure, diversity, and provide species identification. Results indicated volunteers could provide reliable data counting and discerning different tree size classes. However, species identification data was accurate for some species but not for others, and species richness was underrepresented in comparison to professionally collected data. Genera with high species diversity and similar, but slightly different characteristics that distinguished one species from another (*Quercus* and *Ulmus*) were problematic for volunteers and levels of accuracy were statistically significant from the data collected by professionals (Brandon et al., 2003). The purpose of the *ForestWatch* program was to monitor large-scale changes in forest structure and composition; from a practical standpoint, when identification of these complex species were aggregated by genus volunteer reliability increased dramatically. In that sense the volunteer collected data proved useful in providing meaningful information to resource managers.

Volunteer age can also contribute to the ability to collect reliable and accurate data. When monitoring for the presence of native and invasive crab species along the northeast coastline of the United States researchers found differences (15% on average) in the levels of accuracy regarding younger students' ability to reliably collect data related to species identification and gender (Delaney et al., 2007). Younger students (grades three and seven) tended to collect less accurate data pertaining to both parameters, relative to the older students (those with at least two years of university education). A study that utilized students to collect information to assess the age and health of white oak stands in Washington produced similar results that were correlated to student age which displayed greater variation and less reliability in the ability of younger students (grades three through ten) to collect size and crown morphology data (Galloway et al., 2006). In both instances, the authors of each study acknowledged the trade-offs associated with utilizing volunteers, specifically to achieve the detection and prevention purposes of large-scale invasive species monitoring, or providing multiple learning benefits and civic engagement opportunities for students (Galloway et al., 2006; Delaney et al., 2007).

Crall et al. (2011), found volunteer comfort-level (self-identified) was a better predictor of data quality than age, education, or experience. Perception of comfort, or competency, to reliably collect data is often linked to complexity of task (Foster-Smith & Evans, 2003; Brandon et al., 2003) and training provided to volunteers. Providing training and support to volunteers can have significant effects on the levels of volunteer accuracy. When assessing ability to collect credible data pertaining to bird species identification and count, training and testing of volunteers with low to moderate skills levels proved critical (McLaren & Cadman, 1999). The amount and type of training as it relates complexity of task was another important influence on accuracy. The complexity of task underscores the importance of practical training and demonstration. When performing complex and arduous work volunteers without adequate training generally could not complete the tasks (Newman et al., 2003). However, provided sufficient amounts of instruction and supervision, volunteers can produce data comparable to that collected by professional scientists even when the difficulty of the task is increased (Fore et al., 2001; Foster-Smith & Evans 2003; Gillett et al., 2011).

It is also important to consider the type of data parameter and how it is being collected as it pertains to volunteer accuracy and amount of training. Data collection that requires the volunteer to assess subjective measures, as opposed to measureable and objective parameters, can contribute to unreliable results (Galloway et al., 2006); however, comparisons of levels of agreement between professionals can differ widely as well

(Bloniarz & Ryan, 1996; Foster-Smith & Evans, 2003). Limitations of equipment used by volunteer groups to collect certain parameters can contribute to statistical differences between volunteer collected and professionally collected data. However, when using comparable and sophisticated equipment relatively small differences in levels of agreement occurred which suggests volunteers can reliably collect accurate and useful data (Nicholson et al., 2002).

Problem Statement

Information pertaining to the age, condition, and diversity of city street trees are the basis for rational decision-making related to management of urban forests. The costs to collect this fundamental management data can be prohibitive to communities that are lacking the necessary financial and staffing resources to carry out urban forest inventories. Volunteer-driven urban forest survey initiatives can provide data to support sound management of the urban forest, while also providing indirect benefits not realized by outsourcing the survey work, such as increased community engagement and empowerment, advocacy, and knowledge and skill development (Blonairz, 1995; Blonairz & Ryan, 1996; Cozad, McPherson, & Harding, 2005).

Use of volunteers to complete or support maintenance and monitoring activities has been a common component of natural resource management programs across the United States for the past quarter century. Significant evidence exists in the literature to support that trained volunteers can effectively collect data that is comparable in accuracy to data collected by professional scientists as part of monitoring and assessment programming across much of the natural resources disciplines. However, research on the use of volunteers as part of urban forest inventory or survey initiatives is minimal. While there is limited documentation affirming the use of trained volunteers in urban forest survey initiatives there is even less evidence in the literature supporting that trained volunteers can collect urban forest survey data comparable to the quality and accuracy of data collected by professionals. The first objective of this study was to examine the accuracy of volunteer collected urban forest survey data relative to that collected by university research staff and establish whether a high level of agreement between both groups was attained.

Two different training protocols were utilized in the instruction of volunteers who took part in the community tree surveys. The initial training protocol relied on a combination of classroom and field instruction, whereas the second training protocol utilized classroom and field instruction, augmented by mandatory provision of technical assistance. The second objective of this study was to determine the effect training protocol had on the agreement between volunteer collected and university research staff collected data.

Materials and Methods

In 2010, six Minnesota communities were selected to participate in an urban forestry preparedness grant to assess their vulnerability to emerald ash borer (EAB). Eight additional communities were selected in participate in 2011 and 2012. Communities were selected based on population, capacity to manage their urban forest, and location in the four primary ecological provinces as defined in the Minnesota Department of Natural Resources and the U.S. Forest Service Ecological Classification System (Minnesota Department of Natural Resources, 2016). The first set of communities included: Crookston, Hendricks, Hibbing, Hutchinson, Morris, and Rochester. The second set of communities included: Brainerd, Bemidji, Ely, Mankato, Mora, Royalton, Saint Cloud, and Starbuck.

The fourteen Minnesota communities took part in a volunteer-led tree survey to count, identify, and measure both publicly and privately-owned community trees, and condition rate public trees. In each community, areas were selected using the urban street tree rapid sampling technique proposed by Jaenson et al. (1992) which first stratifies and then randomly selects inventory block segments as part of a survey of urban street trees. University of Minnesota researchers modified the Jaenson et al. (1992) sampling protocol to include trees on private property. Due to their small size two communities, Starbuck and Hendricks, completed an inventory of all public street trees, including trees located on boulevards and rights of way. The remaining communities completed inventories of both publicly and privately-owned community trees on randomly selected city blocks as part of a stratified survey.

Volunteer Training

Trained volunteers from each community were enlisted to collect the data necessary for each survey. Volunteer recruitment occurred through press releases in the local community newspaper, and solicitation of master naturalists and master gardeners through email. To assess and validate the data collected by community volunteers, data comparisons were completed by revisiting participating communities, identifying, measuring and condition-rating trees that were initially measured by volunteers as part of the community tree surveys.

Volunteers in each community were trained by research and outreach staff from the University of Minnesota, Department of Forest Resources. Volunteers ranged in age from 18 to 75, level of educational attainment from some high school to doctorate, and from no experience in natural resources to professional experience in natural resources.

Protocol One

All volunteers were trained to perform the same tasks: tree identification, measurement of trunk diameter at breast height (DBH) and crown width, a quantitative condition rating of trees, and how to complete the survey data sheets. Volunteers from the first six communities were trained over the spring and summer of 2010. For these communities, training consisted of approximately a one to one ratio of classroom instruction to field instruction. Training began with six hours of classroom instruction focused on the basics of tree identification concentrating on identifying tree species by their leaves, bark, fruit, and buds. Volunteers were trained to identify trees to species when possible but at least to genus when they were unable to correctly identify species. Every volunteer group was provided custom-made field ID cards for the tree species most prevalent in their community to aid in identification.

Instruction was also provided on how to measure DBH and crown width, as well as how to rate the condition of an individual tree. Condition rating instruction focused on identification and assessment of nine different characteristics to evaluate when rating the condition of a tree, four that were exclusive to canopy condition with the remaining five as trunk condition assessments (see Appendix A for condition rating criteria and descriptions). Volunteers were provided photo ID cards and manuals with images of the defects to serve as examples to aid in identification and assessment.

As a final component of the classroom session volunteers were provided instruction regarding how to properly record data pertaining to tree measurements and location. This was followed by instruction on how to conduct the inventory of individual city blocks that were selected by stratified random sampling as part of the overall community tree survey; this portion of the training took place during the field training session. The two smaller communities had complete inventories of public trees and surveys of privately-owned trees.

Following the classroom instructional session, volunteers were trained how to complete the inventory data sheet and collect data for each metric assessed on individual trees. Volunteers were required to collect data in groups of 2 to 3.

Volunteers were instructed to take measurements of individual tree DBH to the nearest inch, and crown width to the nearest foot. DBH was measured by wrapping a tape measure around the trunk for the tree, at 4.5 feet above ground level. Crown width (CRW) was determined by measuring from one point on the drip line of the tree's crown to the bole of the tree. From the trunk another measurement was taken continuing at a 90-degree angle to a separate point on the opposing point of the tree's drip line created by the angle (USDA Forest Service, 2017). The two crown radii were summed to provide an average crown width. Volunteers paced off the two separate point distances to the drip line from the trunk. Volunteers first measured their individual stride to determine what the equivalent footage was in relation to their number of paces.

To determine a condition rating for each individual tree volunteers were trained to assess certain aspects of both the stem and crown. The following criteria were assessed and given a numeric score. For crown condition: stag-heading, tip die-back, symmetry, and live crown ratio were rated. For trunk condition: cambium loss, presence of exposed and/or decayed wood, sprouts or suckers, stem cracks, and included branch unions were rated. The scores from the stem and crown assessment of each tree were added together to provide a total numeric score for the tree, but individual condition rating for crown and trunk were recorded separately for evaluation. Scores were sorted by range into categories to provide a quantitative ranking of the tree's condition. At the end of training volunteers practiced field data collection with university researchers present to address issues and questions. After training volunteers scheduled their own survey times and teams, with little additional involvement from university researchers during the data collection other than occasional requests for technical assistance, which the researchers responded to via phone or email.

Protocol Two

Training for the remaining eight communities was altered slightly from the training of the first six communities. Training methods, technical assistance, and training manuals were updated and refined based upon feedback and informal assessment from volunteers in the first six communities who underwent training. Training of the volunteers in the second group of communities took place during the summers of 2011 (Brainerd, Bemidji, Mora, Royalton, Saint Cloud, Starbuck) and 2012 (Bemidji, Ely, Mankato). While the ratio of time spent in classroom to field remained the same, as did the training content and sequence, a key difference in training between the first six communities and the following eight was an additional two weeks of technical assistance provided to the second group of communities.

Trainers from the university research and outreach team ("university team") joined the volunteers in the field for the first two weeks of data collection to answer questions as they arose and aid in the data collection protocol. At no time did the university team collect data for the communities. This was intentional on the part of the university team to increase the confidence of the volunteer groups as they began the surveys in their respective communities and help solidify the instruction volunteers received. Another key distinction between Training Protocol 1 and Training Protocol 2 pertained to how crown width was measured. During Training Protocol 1 volunteers paced off the two separate point distances to the drip line from the trunk. However, volunteers who received instruction under Training Protocol 2 used a 50' tape to measure drip line point to trunk for each measurement and then added the two measurements together to determine an average crown width. The 50' measuring tape supplanted the less precise method of measuring crown width by pacing off the distance. Table 1 provides a comparison between the two training protocols.

Table 1. Comparison of difference in training protocols.

	Training topic				
Training protocol	**Species ID**	**DBH**	**CRW**	**Condition rating**	**Manual**
Protocol 1	Classroom & field training	Classroom & field training	Classroom & field training, measured by pace	Classroom & field training	Classroom & field training
Protocol 2	Increased field training, 2 weeks additional technical assistance	Increased field training, 2 weeks additional technical assistance	Increased field training, 2 weeks additional technical assistance, measured by 50’ tape	Increased field training, 2 weeks additional technical assistance	Increased field training, 2 weeks additional technical assistance

Comparison Sampling

Of the 14 participant communities nine communities were revisited for the purpose of assessing the volunteer tree data metrics for agreement with the university team. Only inventoried public trees on block segments were part of the comparison of data metrics between volunteers and the university team due to difficulties in regaining permission to enter private property. Two communities in the Training Protocol 1 group, Crookston and Morris, were excluded due to high volunteer attrition and much of the survey was completed by University of Minnesota researchers, or city personnel. Two communities in the Training Protocol 2 group, Mora and Royalton, were also excluded as too much time (two growing seasons) had lapsed between the initial volunteer survey and potential assessment by the university team. A final community, Bemidji, was excluded because after the initial volunteer survey large portions of the city's urban forest suffered significant damage due to high winds and it would not have been possible to obtain an accurate assessment.

Assessments occurred during the summer months of 2011, 2012, and 2013. For those communities where assessment was not possible in the same growing season an increment borer was used to obtain a core sample. Cored trees were randomly selected from the volunteer-surveyed public trees in eight of the nine communities that were revisited by the university team during the assessment phase. The core samples were measured to verify that the passing of one or several growth seasons did not inadvertently alter the results of the assessing DBH measurements. The measured core samples were used to verify that less than one inch of DBH growth had occurred since the volunteer survey.

Each block inventoried by volunteers during the community tree survey project had both a block map and inventory data sheet(s). Copies of both the block map and data sheet can be found in Appendix B of this study. The completed survey block maps and inventory sheets were used to mark tree locations and denoted whether a tree was residential (privately) or publicly owned. A subsample of trees were randomly selected for assessment by the university team from the volunteer inventory data sheets for each community. Only public trees were sampled for assessment as obtaining permission to access trees on private property in a timely manner was not practical. Obtaining a representative sample of surveyed public trees was crucial to test the accuracy of volunteer measurements. Because the community surveys were designed utilizing a stratified random sampling technique it was vital to maintain a similar sampling technique when determining which public trees to select for accuracy validation. Additionally, proportional sampling, when used in conjunction with stratified, random sampling technique can provide statistically significant and desired representativeness of a population (Van Dalen, 1979). Sample size for comparison between volunteer data and university researcher data was determined using the formula, $s = X^2 NP(1 - P) / d^2 (N - 1) + X^2 P(1 - P)$ (Krejcie & Morgan, 1970). Approximately 90 trees in each of the 9 communities were randomly selected from the volunteer survey data.

The selected trees were identified to species, measurements of DBH and crown width were recorded, and each tree was condition rated by the university team. Assessment of the selected public trees was completed using the same criteria and data collection methods used by volunteers. The data were entered into a Microsoft Excel® spreadsheet and Microsoft Access® database for analysis.

Analysis of the data included comparison of frequency counts and agreement of the taxonomy data between volunteers and the university research and outreach team. Computation of the agreement scores allowed for comparison and examination of the relationship between taxonomic data of the total surveyed tree population collected by the volunteers with sample data collected by researchers. The United States Forest Service has measurement quality objectives (MQO) for genus, species, and DBH consistency rates, however these are intended for professional field inventory crews who collect forest inventory field data as part of Forest Inventory and Analysis (FIA) projects (USDA Forest Service, 2017). In an examination of volunteer accuracy in street tree inventories across two different communities in suburban Boston an 80% agreement level between street tree data collected by volunteers and certified arborists was used as a reasonable threshold for agreement (Bloniarz & Ryan, 1996). For the purposes of this study that same threshold of agreement was maintained as constituting useful and accurate data collection. Due to temporal differences between measurements collected by volunteers and the university team a margin of error was also incorporated into the reasonable threshold for agreement specifically for DBH and CRW. For DBH, volunteer measurements within one (1) inch of the university team assessment were considered as in agreement. For CRW, volunteer measurements within five (5) feet of the university team assessment were considered as in agreement. These margins of error come from predicted growth curves based upon work by Frelich (1992) to project DBH and CRW growth as it correlates with age for city shade trees. Each margin of error accounts for predicted growth span of one year. Chi-square analysis of CRW and DBH was obtained utilizing Microsoft Excel® with significance set at a p-value of 0.05.

Results

Taxonomic results

Assessed trees were identified to the species level, except for the community of Starbuck, which identified trees to the genus level and no agreement data was available at the species level. Frequency tables were calculated for each of the communities surveyed to determine the percentage of agreement between volunteers and the university team. Table 2 illustrates the level of agreement between volunteers and the university team, based upon percentage, organized by genus and species.

Table 2. Genus and species agreement levels between community volunteers and university team.

community	genus agreement	species agreement
Hibbing	98%	40%
Hutchinson	97%	87%
Rochester	98%	79%
Hendricks	97%	58%
Brainerd	95%	72%
Ely	99%	86%
Mankato	99%	81%
Saint Cloud	97%	42%
Starbuck	100%	N/A
All Communities	**98%**	**68%**

At the genus level volunteer agreement percentages with the university training team ranged from 95% to 100%, with a mean level of agreement of 98%, indicating a high level of agreement across all nine communities. At the species level volunteer agreement with the university team was much lower, ranging from 40% to 87%, with a mean of 68%.

Volunteers in the communities of Hibbing, Hutchinson, Rochester, and Hendricks underwent Training Protocol 1 where no scheduled technical assistance was provided to volunteers after the initial combined classroom and field instruction. Table 3 illustrates the level of agreement between volunteers and the university team for those communities who underwent Training Protocol 1. Level of agreement is based upon percentage, organized by genus and species. Volunteers that underwent Training Protocol 1 had a mean level of agreement of 98% with the university team at the genus level. At the species level volunteer agreement values ranged quite substantially from 40% to 87%. For all volunteers who underwent Training Protocol 1 the mean level of agreement with the university team was 66% at the species level.

Table 3. Percent agreement between volunteers and university team by genus & species for Training Protocol 1.

community	genus agreement	species agreement
Hibbing	98%	40%
Hutchinson	97%	87%
Rochester	98%	79%
Hendricks	97%	58%
Training Protocol 1	98%	66%

Table 4 illustrates the level of agreement between volunteers from communities who underwent Training Protocol 2 and the university team. At the genus grouping levels of agreement ranging from 95% to 100% between volunteers and university team across the four communities. The mean level of agreement was 98% at the genus level. Agreement between volunteers and university team at the species level ranged from 42% to 86% across the four communities. The mean level of agreement was 65% at the species level.

Table 4. Percent agreement between volunteers and university team by genus & species for Training Protocol 2.

community	genus agreement	species agreement
Brainerd	95%	72%
Ely	99%	86%
Mankato	99%	81%
Saint Cloud	97%	42%
Starbuck	100%	N/A
Training Protocol 2	98%	65%

Figure 1 represents a comparison of agreement between volunteers and the university team based upon the different training protocols.

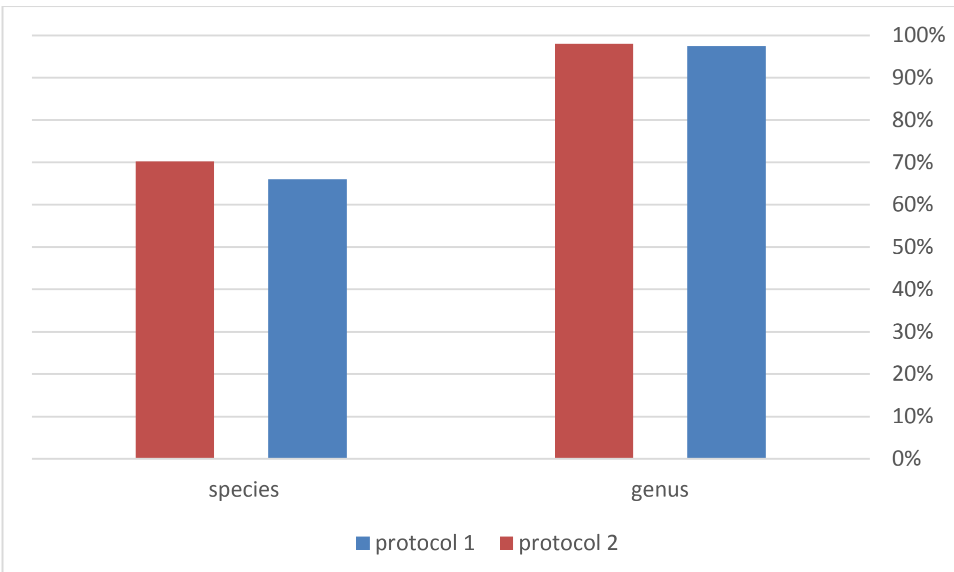


Figure 1. Comparison of percent agreement between training protocols.

DBH and CRW results

Frequency tables were calculated for each of the communities surveyed to determine the percentage of agreement between volunteers and the university team for DBH and CRW. Table 5 illustrates the level of agreement between volunteers and the university team, based upon percentage, organized by DBH, and DBH with a margin of error of one inch.

Table 5. DBH agreement between volunteers and university team.

Community	DBH agreement	DBH agreement +/- 1”
Training Protocol 1		
Hibbing	52%	91%
Hutchinson	52%	80%
Rochester	38%	76%
Hendricks	49%	83%
Training Protocol 2		
Brainerd	58%	85%
Ely	58%	88%
Mankato	53%	94%
Saint Cloud	62%	98%
Starbuck	28%	74%
All Communities	49%	85%

Percentage agreement between volunteers and the university team for DBH measurement ranged quite considerably across the nine communities; at the high-end volunteer measurement agreement with the university team reached 62% in St. Cloud, whereas at the low-end only 28% of the volunteer measurements agreed with those taken by the university team in Starbuck. For the nine communities, the average level of volunteer agreement with the university team was 49%. However, when allowing for a margin of error of only one (1) inch the percentage agreement increased significantly between the two groups. In this instance both the range of values was smaller and the values themselves were higher in level of agreement. With a margin of error of 1” the average level of agreement across the nine communities increased to 85%. The highest agreement was again between volunteers and the university team in St. Cloud (98%), and the lowest level of agreement was in Starbuck (74%).

In the communities that underwent instruction through Training Protocol 1 the volunteer percentage of agreement (46%) with the university team was lower on average than the percentage of agreement between the university team and volunteers who underwent Training Protocol 2 (52%). When a margin of error of 1” was provided, the range of values became smaller and the values increased, but an overall average difference did remain in the level of agreement between volunteers and the university team separated by the two different training modules; under Training Protocol 1 agreement between community volunteers and the university team was lower (82%) than the percentage agreement evident in the groups under Training Protocol 2 (88%).

CRW was the next attribute measured after DBH. Frequency tables were calculated for each of the communities to determine the percentage of agreement between volunteers and the university team. Table 6 illustrates the level of agreement between volunteers and the university team, based upon percentage, organized by CRW, and CRW with a margin of error of five feet.

Table 6. CRW agreement between volunteers and university team.

Community	CRW agreement	CRW agreement +/- 5’
Training Protocol 1		
Hibbing	1%	26%
Hutchinson	13%	67%
Rochester	10%	68%
Hendricks	5%	52%
Training Protocol 2		
Brainerd	7%	68%
Ely	5%	63%
Mankato	53%	99%
Saint Cloud	10%	82%
Starbuck	5%	74%
All Communities	12%	67%

Percentage agreement between volunteers and the university team for CRW measurement ranged considerably across the nine communities; at the high-end volunteer measurement agreement with the university team reached 53% in Mankato, whereas at the low-end only 1% of the volunteer measurements agreed with those taken by the university team in Hibbing. For the nine communities, the average level of volunteer agreement with the university team was 12%. However, when allowing for a margin of error of only five feet the percentage agreement increased significantly between the two groups. In this instance though the range of values was increased the values themselves also were higher in level of agreement. With a margin of error of 5 feet the average level of agreement across the nine communities increased to 67%. The highest agreement (99%) was between volunteers and the university team in Mankato, and the lowest level of agreement was in Hibbing (26%).

In the communities that underwent instruction through Training Protocol 1 which utilized length of stride to determine CRW the volunteer percentage of agreement (7%) with the university team was lower on average than the percentage of agreement between volunteers and the university team for Training Protocol 2 (16%) which used the 50-foot measuring tape to determine CRW. Again, when a margin of error of five (5) feet was provided, the range of values became smaller and the values increased, but a significant overall average difference did remain in the level of agreement between volunteers and the university team separated by the two different training protocols; under Training Protocol 1 agreement between community volunteers and the university team was lower (53%) than the percentage agreement evident in the groups under Training Protocol 2 (77%).

Condition rating results

Condition rating results were organized by four different qualitative categories. The qualitative category and range of scores for each category is provided in Table 7 below.

Table 7. Qualitative categories for tree condition rating.

Tree condition qualitative category	Numeric Score
Excellent	7.5 – 8
Good	5.75 – 7.25
Fair	4.5 – 5.5
Poor	< 4.5

Elements for comparison between the volunteer and university team condition rating assessments are on the following basic agreement matrix displayed on Table 8 below. The numbers represent the total number of trees (770) for all nine communities assessed by both volunteers and the university team. The column on the far right of Table 8 provides totals of the number of trees assessed by the university team to fall within the corresponding condition category, signified by the far left column of the table. The bottom row of the table provides totals of the number of the same trees assessed by volunteers included within the corresponding condition category.

Table 8. Agreement matrix between volunteers and university team for condition rating.

Condition category	*Excellent*	*Good*	*Fair*	*Poor*	**TOTAL (University Team)**
Excellent	257	72	10	2	341
Good	147	151	13	5	316
Fair	12	28	12	4	56
Poor	4	23	15	15	57
TOTAL (Volunteers)	420	274	50	26	770

In assessing condition volunteers found 33% of the total surveyed trees to be in excellent condition, while the university team found a slightly higher percentage (44%) to be in excellent condition. This corresponded to a level of agreement of 75% between volunteers and the university team. Of the 341 trees the university team rated in excellent condition only 257 trees were rated as excellent by the volunteers; of the remainder volunteers rated 72 trees in good condition, 10 in fair, and 2 in poor. Volunteers found 20% of the total surveyed trees to be in good condition, while the university team assessed a higher percentage (41%) to be in good condition which corresponded to 48% level of agreement. Of the 316 trees the university team assessed to be in good condition, volunteers only agreed this to be the case with 151 trees, and instead with the remainder rated 147 trees in excellent condition, 13 trees in fair condition, and 5 trees in poor condition. For trees in fair condition volunteers agreed with the university team 21% of the time. Here, of the 56 trees the university team found to be in fair condition, volunteers determined only 12 of those to be rated as fair, and observed 28 to instead be in good condition, 12 in excellent condition, and 4 were in poor condition. For trees in poor condition agreement increased slightly to 26%. The university team had rated 57 trees to be in poor condition, however volunteers agreed with only 15 of those same trees as being in poor condition and observed 4 to instead be in excellent condition, 23 in good condition, and 15 were rated as in fair condition.

When looking at overall agreement for tree condition across all nine communities, volunteers' assessment of condition coincided 56% (435 trees) of the time with the assessment made by the university team. Comparing the two training protocols, volunteers in the communities who underwent Training Protocol 2 had a slightly higher level of agreement (62%) with the university team regarding tree conditions, as opposed to volunteers from communities who went through Training Protocol 1 where the level of agreement with the training team was 50%.

Chi-Square Test Results

Agreement matrices provide a useful illustration of the pragmatic accuracy of the volunteer-collected data from this research effort, however it is also possible to show the statistical agreement of volunteer-collected data relative to the university training team utilizing the Chi-square statistical test. Chi-square is a statistical test which can be used to compare the probability of results, specifically the deviation of observed results from expected results. By determining the probability value (p-value) associated with the observed and expected results of the survey data set it is possible to indicate at certain levels of significance whether the deviation is due to some cause, or due only to chance alone. In the absence of actual measurement data, such as was the case with the condition rating of trees by volunteers and the university team, the Chi-square test can be used to indicate if there is a statistical difference that exists between the two groups. It can be used to reject or accept the null hypothesis. In this research study the null hypothesis is that there is no statistical difference between the condition assessments provided by the volunteers and the university team. Table 9 below displays the calculated Chi-square score from the condition assessment data for all community volunteers, and the tabular Chi-square with 3 degrees of freedom at a significance level of 0.05.

Table 9. Calculated & tabular Chi-square score for condition assessment for all communities.

Degrees of freedom	Calculated Chi-square	Tabular Chi-square	Significance level
3	41.39	7.82	0.05

Because the calculated value is greater than the tabular value the null hypothesis can be rejected. This would indicate there is a statistical difference between the condition assessment data collected by all volunteers from that collected by the university team.

Table 10 below displays the calculated Chi-square score from the condition assessment data for the two different training protocols. Because the calculated value is greater than the tabular value, the null hypothesis can be rejected for Training Protocol 1. This would indicate there is a statistical difference between the condition assessment data collected by volunteers who received Training Protocol 1 and the university team. However, for Training Protocol 2 the null hypothesis cannot be rejected. The calculated value is less than the tabular value, indicating there is no statistical difference between condition assessment data collected by volunteer who received Training Protocol 2 and the university team.

Table 10. Calculated & tabular Chi-square score for condition assessment by training protocol.

Training Protocol	Degrees of freedom	Calculated Chi-square	Tabular Chi-square	Significance level
Protocol 1	3	41.84	7.82	0.05
Protocol 2	3	6.45	7.82	0.05

In this study, a Chi-square test was also used to examine the statistical level of agreement between volunteers and the university team for measurement of DBH and CRW. Previous studies (Bloniarz & Ryan, 1996) have shown that even certified, professional arborists can differ significantly from one another in their assessment of taxonomic identification and tree condition. It is wholly plausible that differences of assessment could extend to measurement of tree crown width and diameter. However, for this assessment it was assumed that the university team measurements of DBH and CRW were the accepted standard of accuracy, and the volunteer measurements were the object of testing. Further, to evaluate the accuracy of volunteer measurement relative to the university team it was necessary to determine the threshold of accuracy necessary. In other words, how much inaccuracy could be tolerated before the measurement was not found to be useful.

For DBH accuracy of measurement was determined to be any measurement within one (1) inch of the university team's measurement. Tabular values were computed for measurement increments of one (1) inch, two (2) inches, and three (3) inches, with the corresponding degrees of freedom, and at a significance level of 0.05. For each community, and for all communities in aggregate, a Chi-square value for volunteer measurement of DBH was calculated. The accuracy of a measurement technique was rejected if the calculated value for was greater than the tabular value. Table 11 displays the results of the Chi-square test for DBH measurement below.

Table 11. Calculated & tabular Chi-square score for DBH.

Community	Degrees of Freedom	Calculated Chi-square			Tabular Chi-square (p=0.05)
		(1-inch)	(2-inch)	(3-inch)	
Brainerd	97	113.37	28.34	12.60	120.99
Ely	138	162.15	40.54	18.02	166.42
Hendricks	91	220.23	55.06	24.47	114.27
Hibbing	86	146.18	36.54	16.24	108.65
Hutchinson	60	182.39	45.60	20.27	79.08
Mankato	68	28.62	7.15	3.18	88.25
Rochester	79	144.59	36.15	16.07	100.75
Saint Cloud	88	34.08	8.52	3.79	110.90
Starbuck	55	54.55	13.64	6.06	74.47
All Communities	**779**	**1086.16**	**271.54**	**120.68**	**845.04**

The calculated Chi-square value for all volunteers' measurement of DBH within one (1) inch of agreement was 1086.16. Because this was larger than the tabular value (845.04) it indicates that volunteers did not meet a statistically acceptable level of agreement, even with a margin of error of one (1) inch. However, though the results suggest a statistical difference in the measurement of DBH by volunteers from that of the university team, the volunteer data does fall above a threshold of 80% agreement, as indicated in table 5 above, and therefore, from a pragmatic approach is determined to be useful and accurate.

Table 12. Calculated & tabular Chi-square score for DBH across both training protocols.

Training Protocol	Degrees of Freedom	Calculated Chi-square			Tabular Chi-square (p=0.05)
		(1-inch)	(2-inch)	(3-inch)	
Protocol 1	322	693.39	173.35	77.04	364.85
Protocol 2	455	392.77	98.19	43.64	505.73

Assessing the results when comparing volunteer measurements based upon training protocol suggests that volunteers in communities who underwent Training Protocol 2 were slightly more accurate than their volunteer counterparts who went through Training Protocol 1. Volunteers under Training Protocol 2 were accurate within a margin of error of one (1) inch, whereas volunteers from Training Protocol 1 needed a two-inch margin of error to meet the desired level of agreement with the university team, as indicated on table 12 above. However, in both groupings volunteers still exceeded a level of agreement greater than 80% with the university team, as shown in table 5.

For CRW accuracy of measurement was determined to be any measurement within five (5) feet of the university team's measurement. Tabular values were computed for measurement increments of one (1) foot, two (2) feet, three (3) feet, and four (4) feet with the corresponding degrees of freedom, and at a significance level of 0.05. For each community, and for all communities in aggregate, a Chi-square value for volunteer measurement of CRW was calculated. The accuracy of a measurement technique was rejected if the calculated value for was greater than the tabular value. Table 13 displays the results of the Chi-square test for CRW measurement.

Table 13. Calculated & tabular Chi-square score for CRW.

Community	Degrees of Freedom	Calculated Chi-square				Tabular Chi-square (p=0.05)
		(1-foot)	(2-feet)	(3-feet)	(4-feet)	
Brainerd	97	382.55	95.64	42.51	23.91	120.99
Ely	138	792.89	198.22	88.10	49.56	166.42
Hendricks	91	1339.85	334.96	148.87	83.74	114.27
Hibbing	86	1719.57	429.89	191.06	107.47	108.65
Hutchinson	60	520.11	130.03	57.79	32.51	79.08
Mankato	68	372.60	93.15	41.40	23.29	88.25
Rochester	79	654.15	163.54	72.68	40.88	100.75
Saint Cloud	88	393.30	98.32	43.70	24.58	110.90
Starbuck	55	540.37	135.09	60.04	33.77	74.47
All Communities	**779**	**4863.77**	**1215.94**	**303.99**	**194.55**	**845.04**

The calculated Chi-square value for all volunteers' measurement of CRW at five (5) feet was 194.55. Because this was smaller than the tabular value (845.04) it indicates that volunteers did meet a statistically acceptable level of accuracy, even with a margin of error of five (5) feet.

Table 14. Calculated & tabular Chi-square score for CRW across both training protocols.

Training Protocol	Degrees of Freedom	Calculated Chi-square				Tabular Chi-square (p=0.05)
		(1-foot)	(2-feet)	(3-feet)	(4-feet)	
Protocol 1	322	4233.68	1058.42	470.41	264.60	364.85
Protocol 2	455	2481.70	620.43	275.74	155.11	505.73

Assessing the results when comparing volunteer measurements based upon training module suggests that volunteers in communities who underwent Training Protocol 2 were slightly more accurate than their volunteer counterparts who went through Training Protocol 1. Volunteers under the Training Protocol 2 were accurate within a margin of error of three (3) feet, whereas volunteers from Training Protocol 1 needed a four-foot margin of error to meet the desired level of accuracy (the university team measurement), as indicated on table 14 above.

Discussion

A tree inventory or survey is of key importance to sustainable management and stewardship of the urban forest. Lack thereof, or inaccurate, information related to the age, quality, and type of forest resources contributes to uncertainty regarding what management decisions are necessary for a resource manager to make to sustain or improve the health of the urban forest. Data gathered from an urban forest inventory or survey provides fundamental information necessary to make informed management decisions related to maintenance schedules and priorities, budget allocations, and future needs. This supports a paradigm shift in management from a purely reactionary endeavor to something that is more intentional, informed, and proactive.

The results of this research indicate that trained volunteers can collect “acceptably accurate” data on municipal trees as part of an urban forest survey. The results also provide evidence that volunteer collected urban forest survey data can attain a level of agreement that is comparable to data collected by the university team, trained and experienced assessment and measurement of urban trees. The implications of these findings carry substantial weight, especially for communities that lack the financial, administrative, or technical resources that are otherwise necessary to provide similar information about their urban forest.

Tree Identification

Across all nine communities volunteer tree identification to the genus level attained levels of agreement that were consistent with the university team. The results also displayed a very tight range of agreement values across all nine communities, and training modules. These results for genus identification were similar, or exceeded, results of past studies (Bloniarz & Ryan, 1996; Roman et al., 2017). Species level identification presented more mixed results, with community averages below levels of agreement found at the genus level, and wider ranging percentage values of agreement across different communities, even within those who received the same training protocol. The community volunteers who received training under Training Protocol 1 had levels of agreement with the university team as low as 40% (Hibbing) and as high as 87% (Hutchinson). This range of agreement values was also present in results from volunteers who underwent Training Protocol 2; 86% (Ely) to 42% (St. Cloud). However, species level identification agreement rates by volunteers in this study were similar to past research efforts (Bloniarz & Ryan, 1996; Cozad et al., 2005; Romans et al., 2017). The cause for such wide ranges of percentage agreement across communities is not certain. Complexity of urban forest species conditions did not seem to matter; Hutchinson and Rochester had the most diverse urban forest based upon family, genera, and species distributions, but their level of species identification agreement were among several of the higher across the nine communities, at 87% and 79%, respectively. Differences in instruction did not appear to contribute either as ranges in value were similar across both training modules. Volunteer demographic data, not available or analyzed by this study, warrants further examination to explore possible influence of tree identification results.

Despite falling short of the MQO set forth by the U.S. Forest Service FIA thresholds for urban forests (2017) the volunteers in this study still exceeded or meet accuracy thresholds set forth by earlier studies. The results of this study, as they pertain to tree identification, need to be contextualized in light of present threats to Minnesota’s urban and community forests. Invasive insect species that currently pose threats to the forests and woodlands of Minnesota include emerald ash borer (*Agrilus planipennis*) and gypsy moth (*Lymantria dispar)*. Emerald ash borer will utilize all three (white ash, green ash, and black ash) of the predominant native species of the *Fraxinus* genus found in Minnesota's urban forests as hosts, while gypsy moth will defoliate hundreds of species of plants, albeit oaks and aspen tend to be more common tree hosts (USDA Forest Service, 2017). Asian longhorned beetle (*Anoplophora glabripennis*), not yet present in Minnesota, primarily utilizes trees in the *Acer* genus as its preferred host (Minnesota Department of Agriculture, 2017). Volunteer ability to accurately identify trees to a minimum level of genera is encouraging and warrants pragmatic considerations, especially for resource managers as knowledge of genus level diversity will likely prove adequate to assess potential canopy losses, or insecticide treatment costs needed to formulate management objectives based upon projections from tree survey/inventory data.

DBH and CRW

Measurements of DBH and CRW by volunteers were somewhat more mixed in their levels of agreement with measurements taken by the university team. Volunteer DBH agreement compared favorably with similar studies (Cozad et al., 2005; Roman et al., 2017) however, both DBH and CRW measurement levels of agreement fell below FIA thresholds. Interestingly, results indicated that volunteers did meet a statistically acceptable level of accuracy, even with a margin of error of five (5) feet, as was evidenced by p-value scores. Though the DBH agreement values of the volunteers who underwent Training Protocol 1 were slightly lower than those who received Training

Protocol 2 the differences are slight enough to imply that different training protocols had a minimal effect upon volunteer ability to accurately measure DBH. However, for CRW, different training protocols did produce a noticeable difference between volunteers. The community volunteers who underwent Training Protocol 2 had significantly higher levels of measurement agreement with the university team than did those volunteers underwent Training Protocol 1. The reasons for the observed differences in agreement are likely attributable to training differences in the measurement technique of CRW. During Training Protocol 1 volunteers were instructed to pace off the two radial measurements used to determine CRW, whereas during Training Protocol 2 volunteers used a 50’ tape measure to collect the radial measurements. The tape measure provided a more objective and consistent tool of measurement as opposed to the pace of the individual volunteer or university team member, which was subject to errors of precision.

Across different communities and training protocols CRW was still generally lower in level of agreement. Environmental factors, such as wind, could have contributed to discrepancies between CRW measurements made by volunteers and the university team. However lower levels of agreement are probably best explained by the lack of defined standard radial measurement orienteering points during volunteer instruction. Instead of instructing volunteers to measure the north and east radii of an individual tree’s crown, volunteers could choose which two radii to measure if it formed a 90-degree angle. The CRW radii measurement points were not noted on any data collection sheet, resulting in university team measurements of different radii than volunteers used to assess the CRW. Differences in crown radii selection was a likely limitation to assessment of volunteer accuracy regarding tree CRW. Volunteer training, and assessment, would benefit from revised CRW measurement instruction indicating designated measurement points.

Condition rating

Condition rating agreement was both statistically and pragmatically different between volunteers and the university team. Interestingly, Chi-square analysis indicated statistical differences between volunteers who received Training Protocol 1 and the university team, yet no statistical difference was evident between volunteers who received Training Protocol 2 and the university team. Volunteers who received Training Protocol 2 also had higher levels of agreement with the university team than their counterparts who received Training Protocol 1. This suggests the additional technical service provided by the university team to volunteers as part of Training Protocol 2 had a positive effect on levels of agreement pertaining to condition rating. One of the two major distinctions between the volunteer and university team condition rating data is that the volunteers tended to be more conservative in their estimate of condition, especially regarding trees in excellent condition. Of the 341 trees the university team rated in excellent condition only 257 trees were rated as excellent by the volunteers. The second major distinction between the condition rating data of the volunteers and university team is as it relates to trees in increasingly deteriorating condition. The amount of agreement between volunteers and the university team declined significantly as tree condition worsened. Compared to the university team, volunteers found a third less of the surveyed trees to be in fair or poor condition. This could be attributable to the temporal difference between data collected by the volunteers and the university team. Because the university team collected data on the same trees a year after the volunteers had assessed the conditions the passage of time could have allowed for tree conditions to deteriorate between these two periods, which could be exacerbated in trees with fair to poor condition ratings where deterioration may rapidly accelerate. Had the data collection by the university team been concurrent with the volunteer groups in each community the level of agreement may have been higher. Further research efforts should make every attempt to conduct quality control assessment at the same time, or shortly thereafter, to reduce the possibility of temporal effects on the validity of data. While condition rating data collected by volunteers might prove useful as an indication of general concerns, management objectives and activities would also benefit from follow-up by a professional arborist who is experienced in condition rating. In this sense volunteer condition rating data provides useful information about possible trends which can help to focus and direct management efforts.

It is important to note the utility of the Chi-square test in analysis of the volunteer and university team data in light of the temporal difference in data collection. A paired T-test is often useful to compare two different but correlated populations, or "before-after" measurements, and it might appear to be a useful measure to assess the statistical accuracy of the volunteers in relation to the university team when measurement data is available. However, in this instance utilizing the T-test would be a misapplication of the statistical measure it provides as it uses one form of accuracy (precision) to test for the other form (freedom from bias) which can lead to the rejection of an accurate measurement (Freese 1960). In the presence of actual measurement data, or parametric data, it is also possible to use the Chi-square test to verify the accuracy of a measuring technique against an accepted standard as the Chi-square test will reject an inaccurate measurement regardless of the source of inaccuracy, be it bias or lack of precision.

Several uncontrolled factors not accounted for in the study design might have also influenced perceived “adequate accuracy” and volunteer levels of agreement. The involvement of city personnel in survey activities possibly contributed to increased levels of agreement. Across the nine study communities participation by city personnel varied. In some instances, municipal staff from the parks and recreation department were involved in the survey data collection. A few municipalities had designated urban or community foresters who actively took part in data collection and training sessions. Other communities lacked any designated city staff and relied on one or several volunteers to take the administrative lead. Communities where city personnel participation was high (Hutchinson, Rochester, Mankato, St. Cloud) might have benefited from additional technical support that was intrinsically linked to city staff involvement.

In other instances deviation from training protocol instruction might have skewed results in one direction or another. In some communities, despite recommendations from the university team, several volunteers went out alone to collect survey data. Additionally, some volunteer team members tended to be “botanical bullies”, disregarding the assessments of other team members, influencing the collective team assessment to align with their own. In the cases where the individual assessment was biased this distorted data collection, the team assessment suffered, and levels of agreement were potentially impacted.

A final factor not controlled by this study that might have influenced results can be attributed to “data fatigue”. Complex, detailed, or arduous tasks can contribute to frustration and boredom on the part of the volunteer, which have negative ramifications for the quality of data collection (Darwall & Dulvy, 1996; Newman et al., 2003). If volunteers became unengaged in the task at hand, or lost their sense of objectivity in data collection bias and/or imprecision could have been introduced into the data and influenced results.

Smaller communities often have difficulty implementing urban forest management practices. Most often this is due to challenges in finding support and time, a lack of resources, and uncertainty regarding responsibility and authority pertaining to management. Effective urban forestry programs promote the importance and value of urban forests, seek to include a range of involvement across the community, and acknowledge the shared responsibility of both public and private interests in resource management (Elmendorf et al., 2003). Volunteers are a way to bridge the capacity gap that exists in many communities to help address urban forest management concerns. The benefits of incorporating volunteers are recognized as two-fold: Volunteers help to communicate information necessary to the urban forester for management decisions and the volunteers in turn receive important educational and programmatic information regarding the maintenance and care for their community’s forest (Westphal, 1993).

Vibrant community forestry programs effectively use volunteers to develop, promote and maintain healthy urban forests. Successful programming is predicated on educating and raising awareness of the participants regarding the importance of healthy community forests. Effectively using volunteers also creates an additional source of information and communication to the larger community. Engagement and empowerment of volunteers within communities can also be harnessed by municipal foresters, resource managers, and decision makers to leverage funding, or impact policy that benefits the urban forest (Bloniarz & Ryan, 1996).

Summary and conclusions

To mitigate declining and lost sources of capacity, agencies and local governments are increasingly relying on volunteers to carry out activities to meet programmatic goals. A large body of work has helped to establish and support the use of volunteers to effectively assess and monitor natural resources (Penrose & Call, 1995; Rock & Lauten, 1996; McLaren & Cadman, 1999; Brown et al., 2001; Fore et al., 2001; Nicholson et al., 2002; Engel & Voshell, 2002; Delaney et al., 2007; Crall et al., 2011; Gillett et al., 2011). Volunteers can play a vital role in collecting acceptably accurate, necessary data that is part of a natural resource inventory.

Urban and community forestry programs have often benefited from the utilization of volunteers to develop, promote and maintain healthy urban forests through activities geared towards tree plantings and maintenance. The use of volunteers as part of an urban forest inventory effort can be an effective way to efficiently gather basic information related to tree density, condition, and age to guide management decisions to enhance and sustain the urban forest and the benefits it provides to a community. Despite the large amount of evidence to support the use of volunteers as part of natural resources assessment and monitoring initiatives there is very little in the literature to support the use of community volunteers in urban tree inventory or survey initiatives. The efforts of this study augment and build upon what little research exists supporting the use and accuracy of volunteers in urban forest inventories. Volunteer-driven urban forest inventory and survey initiatives can provide useful and acceptably accurate data to support sound management of the urban forest at a fraction of the cost, while also providing indirect benefits not realized by outsourcing the survey work.

Resource managers who undertake volunteer-driven urban forest inventory or survey initiatives play a crucial role as administrator and technical support provider. Adapting and improving volunteer training is important to any forest inventory or survey initiative. Though not directly addressed by this research, evidence indicates dynamic training that is responsive to expressed needs and concerns improves the experience of the volunteer participant (Hager & Brudney, 2004; Leslie et al., 2004; Simes, 2006; Fernandez-Gimenez, Ballard, Sturtevant, 2008). Differences observed in this study between the two training protocols indicate increased provision of technical support had a noticeable effect on the level of agreement between trained volunteers and the university research team. Providing adequate technical support will improve the quality of the data, increasing its usefulness to any management efforts.

Beyond providing adequate and useful data that will meet the needs of management and monitoring programs utilizing volunteers can also have profound positive impacts for communities through increased civic engagement or momentum-building towards future management efforts (Bloniarz & Ryan, 1996; Nicholson et al., 2002; Foster-Smith & Evans, 2003; Galloway et al., 2006), leveraging of limited budgets (Mattson et al., 1994; Brown et al., 2001), and expansion data collection on large temporal and spatial magnitudes that would otherwise be beyond the capability of most scientific endeavors (Dickinson et al., 2010).

Works Cited

Ball J. (1986). Urban forestry and volunteer management. *Journal of Arboriculture, 12* (7), 182-184.

Bloniarz, D.V., & Ryan, D.P. (1996). The use of volunteer initiatives in conducitng urban forest resource inventories. *Journal of Arboriculture, 22,* 75-82.

Brack, C.L. (2002). Pollution mitigation and carbon sequestration by an urban forest. *Environmental Pollution, 116,* 195-200.

Brandon, A., Spyreas, G., Molano-Flores, B., Carroll, C., & Ellis, J. (2003). *Natural Areas Journal*, *23*(23), 254-262.

Brown, W.T., Krasny, M.E., & Schoch, N. (2001). Monitoring of nonindigenous invasive plant species in Adirondack Park, New York, USA. *Natural Areas Journal, 21*(2), 189-196.

Cozad, S., McPherson, E.G., & Harding, J.A. (2005). *STRATUM case study evaluation in Minneapolis, MN*. Davis: University of California, Davis,

Crall, A.W., Newman, G.J., Stohlgren, T.J., Holfelder, K.A., Graham, J., & Waller, D.M. (2011). Assessing citizen science data quality: an invasive secies case study. *Conservation Letters, 4,* 433-442.

Darwall, W.R.T., & Dulvy, N.K. (1996). An evaluation of the suitability of non-specialist volunteer reserachers for coral reef fish surveys. *Biological Conservation*, *78*, 223-231.

Delaney, D.G., Sperling, C.D, Adamns, C.S., & Leung, B. (2007). Marine invasive speciecs: validation of citizen science and implications for national monitoring networks. *Biological Invasions, 10*(1), 117-128.

Dickinson, J.L., Zuckerberg, B., & Bonter, D.N. (2010). Citizen science as an ecological research tool: challenges and benefits. *The Annual Review of Ecology, Evolution, and Systematics, 41*, 149-172.

Dwyer, J. F. (1995). The significance of trees and their management in built environments, in *Trees and Building Sites: Proceedings of an International Conference held in the Interest of Developing a Scientific Basis for Managing Trees in Proximity to Buildings* (G. Watson, and D. Neely, eds.), International Society of Arboriculture, Savoy, IL, pp. 3–11.

Elmendorf, W.F., Cotrone, V.J., & Mullen, J.T. (2003). Trends in urban forestry practices, programs, and sustainability: contrasting a Pennsylvania, U.S., study. *Journal of Arboriculture, 29*(4), 237-248.

Engel, S.R., & Voshell Jr., J.R. (2002). Volunteer biological monitoring: can it accurately assess the ecological condition of streams. *American Entomologist, 48*(3), 164-177.

Fernandez-Gimenez M.E., Ballard, H.L., & Sturtevant, V.E. (2008). Adaptive management and social learning in collaborative and community-based monitoring: a study of five community-based forestry organizations in the western USA. *Ecology and Society*, *13*(2), 4.

Fitzpatrick, M.C., Preisser, E.L., Ellison, A.M., Elkinton, J.S. (2009). Observer bias and the detection of low-density populations. *Ecological Applications. 19*(7), 1673–1679.

Fore, L.S., Paulsen, K., O'Laughlin, K. (2001). Assessing the performance of volunteers in monitoring streams. *Freshwater Biology, 46*, 109-123.

Foster-Smith, J., & Evans, S.M. (2003). The value of marine ecological data collected by volunteers. *Biological Conservation, 113*, 199-213.

Freese, F. (1960). Testing accuracy. *Forest Science*, *6*(2), 139-145.

Frelich, L.E. (1992). *Predicting dimensional relationships for Twin Cities shade trees*. St. Paul: Department of Forest Resources, University of Minnesota-Twin Cities.

Galloway, A.W.E., Tudor, M.T., & Vander Haegen, W.M (2006). The reliability of citizen science: a case study of Oregon white oak stand surveys. *Wildlife Society Bulletin, 34*(5), 1425-1429.

Gibbons, K.H., & Ryan, C.M. (2015). Characterizing comprehensiveness of urban forest management plans in Washington State. *Urban Forestry & Urban Greening, 14*, 615-624.

Gillett, D.J., Pondella, D.J., Freiwald, J., Schiff, K.C., Caselle, J.E., Schuman, C., & Weisberg, S.B. (2012). Comparing volunteer and professionally collected monitoring data from the rocky subtidal reefs of Southern California, USA. *Environmental Monitoring and Assessment, 184*(5), 3239-3257.

Hager, M.A., & Brudney, J.L. (2004). *Volunteer management practices and retention of volunteers*. Washington, D.C: The Urban Institute.

Hauer, R.J., & Johnson, G.R. (2008). State urban and community forestry program funding, technical assistance, and financial assistance within the 50 United States. *Arboriculture & Urban Forestry, 34*(5), 280-289.

Heiskary, S., Lindbloom, J., & Wilson, C.B. (1994). Detecting water quality trends wih citizen volunteer data. *Lake and Reservoir Management, 9*(1), 4-9.

Jack-Scott, E., Piana, M., Troxel, B., Murphy-Dunning, C., & Ashton, M.S. (2013). Stewardship success: how community group dynamics affect urban street tree survival and growth. *Arboriculture & Urban Forestry, 39*(4), 189-196.

Jaenson, R., Bassuk, N., Schwager, S., & Headley, D. (1992). A statistical method for the accurate and rapid samping of urban street tree populations. *Journal of Arboriculture, 18*(4), 171-183.

Jorgensen, E. (1986). Urban forestry in the rearview mirror. *Arboricultural Journal, 10,* 177-199.

Kaplan, R. (2004). The social value of forests and trees in urbanised societies. In Konijnendijk, C.C., Schipperijn, J., Hoyer, K.K (eds.), *Selected papers from the conference on Forestry Serving Urbanised Societies* (167 - 178). Vienna: IUFRO.

Kinney, J.P. (1972). *The development of forest law in America including legislation in America prior to March 4, 1789*. (Reprint of the original 1917, first edition, and published by John Wiley and Sons, Inc., New York.) New York: Arno Press.

Konijnendijk, C.C. (1997). A short history of urban forestry in Europe. *Journal of Arboriculture*, *23*(1), 31-39.

Konijnendijk, C.C., Richard, R.M., Kenney, A., & Randrup, T.B. (2006). Defining urban forestry - a comparative perspective of North America and Europe. *Urban Forestry & Urban Greening*, *4*(3-4), 93-103.

Krejcie, R.V., & Morgan, D.W. (1970). Determining sample size for research activities. *Educational and Psychological Measurement, 30*, 607-610.

Kuo, F.E. (2003). Social aspects of urban forestry: the role of arboriculture in a healthy social ecology. *Journal of Arboriculture, 29*(3), 148-155.

Leslie, L.L., Velez, C.E., & Bonar, S.A. (2004). Utilizing volunteers on fisheries projects. *Fisheries, 29*(10), 10-14.

Makra, E.M., & Andresen J.W. (1990). NeighborWoods: volunteer community forestry in Chicago. *Arboricultural Journal, 14*(2), 117-127.

Mattson, M.D., Walk, M.F., Kerr, P.A., Slepski, A.M., Zajicek, O.T., & Godfrey, P.J. (1994). Quality assurance testing for a large scale volunteer monitoring pogram: the acid rain monitoring project. *Lake and Reservoir Management, 9,* 10-13.

McLaren, M.A., & Cadman, M.D. (1999). Can novice volunteers provide credible data for bird surveys requiring song identification? *Journal of Field Ornithology, 70* (4), 481-490.

McPherson, E.G. (1994). Energy-saving potential of trees in Chicago. In McPherson, E.G., Nowak, D.J., & Rowntree, R.A. (Eds.), *Chicago's urban forest ecosystem: results of the Chicago urban forest climate project* (pp. 95-114). Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station.

McPherson, E.G., Simpson, J.R., Peper, P.J., Maco, S.E., & Xiao, Q. (2005). Municipal forest benefits and costs in five U.S. cities. *Journal of Forestry, 103*(8), 411-416.

Miller, R.W. (1997). *Urban Forestry: planning and managing urban greenspaces*. (2^{nd} ed.). New Jersey: Prentice Hall.

Minnesota Department of Agriculture. (2017). *Landscape pests*. Retrieved from http://www.mda.state.mn.us/plants/pestmanagement/invasivesunit/pestinformation/landscapepests.aspx.

Minnesota Department of Natural Resources. (2016, December). *Ecological Classification System*. Retrieved from Minnesota Department of Resources: http://www.dnr.state.mn.us/ecs/index.html.

Newman, C., Buesching, C.D., & Macdonald, D.W. (2003). Validating mammal monitoring methods and assessing the peformance of volunteers in wildlife conservation - "Sed quis custodiet ipsos custodies?". *Biological Conservation, 113*, 189-197.

Nicholson, E., Ryan, J., & Hodgkins, D. (2002). Community data-where does the value lie? Assessing confidence limits of community collected water quality data. *Water Sciecne and Technology*, *45*(11), 193-200.

Nowak, D.J. (1994). Carbon dioxide reduction removal by Chicago's urban forest. In McPherson, E.G., Nowak, D.J., & Rowntree, R.A. (Eds.), *Chicago's urban forest ecosystem: results of the Chicago urban forest climate project* (pp. 83-94). Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station.

Nowak, D.J., Hoehn, R.E. III, Crane, D.E., Stevens, J.C., Walton, J.T. (2006). *Assessing urban forest effects and values, Minneapolis' urban forest*. Resour. Bull. NE-166. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station.

Nowak, D.J., & Dwyer, J.F. (2007). Understanding the benefits and costs of urban forest ecosystems. In Kuser, J.E. (ed.), *Urban and Commuity Forestry in the Northeast* (2nd ed.) (25-46). New Brunswick: State University of New Jersey.

Payton, S., Lindsey, G., Wilson, J., Ottensmann, J.R., & Man, J. (2008). Valuing the benefits of urban forest: a spatial hedonic approach. *Journal of Environmental Planning and Management*, *51*(6), 717-736.

Penrose, D., & Call, S.M. (1995). Volunteer monitoring of benthic macroinvertebrates: regulatory biologists' perspectives. *Journal of the North American Benthological Society, 14*(1), 203-209.

Ricard, R.M. (2005). Shade trees and tree wardens: Revising the history of urban forestry. *Journal of Forestry 103*(5), 230-233.

Robbins, W.G. (1985). *American forestry: A history of national, state, and private cooperation*. Lincoln: University of Nebraska.

Rock, B.N., & Lauten, G.N. (1996). K-12th grade students as active contributors to research investigations. *Journal of Science Education and Technology, 5*(4), 255-266.

Roman, L.A., Scharenbroch, B.C., Östberg, J.PA., Mueller, L.S., Hennins, J.G., Koeser, A.K., Sanders, J.R., Betz, D.R., & Jordan, R.C. (2017). Data quality in citizen science urban tree inventories. *Urban Forestry & Urban Greening, 22,* 124-135.

Rosenfeld, A.H., Romm, J.J., Akbari, H., & M. Pomerantz. (1998). Cool communities: strategies for heat islands mitigation and smog reduction. *Energy and Buildings*, *28*, 51-62.

Rowntree, R.A., McPherson, E.G., & Nowak, D.J. (1994). Th role of vegetation in urban ecosystems. In McPherson, E.G., Nowak, D.J., & Rowntree, R.A. (Eds.), *Chicago's urban forest ecosystem: results of the Chicago urban forest climate project* (pp. 1-2). Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station.

Simes, C. (2006). Reconsidering the role of training in event volunteers' satisfaction. *Sport Management Review*, *9*, 165-182.

Simpson, J.R. (1998). Urban forest impacts on regional cooling and heating energy use: Sacramento County case study. *Journal of Arboriculture*, *24*(4), 201-214.

Topp-Jorgensen E., Poulsen M.K., Lund, J.F., & Massao J.F. (2005). Community-based monitoring of natural resource use and forest quality in montane forests and miombo woodlands of Tanzania. *Biodiversity and Conservation*, *14*, 2653-2677.

US Forest Service. (2017). Forest Inventory and Analysis National Urban Plot FieldGuide: Field Data Collection Procedures for Urban FIA Plots, Version 7.1. USDA Forest Service, Northern Research Station, Available at: http://www.nrs.fs.fed.us/fia/urban.

Van Dalen, D. B. (1979). *Understanding educational research.* New York: McGraw Hill, Inc.

Vogt, J., Hauer, R.J., & Fischer, B.C. (2015). The costs of maintaining and not maintaining the urban forest: a review of the urban forestry and arboriculture literature. *Arboriculture & Urban Forestry, 41*(6), 293-323.

Westphal L.M. (1993). Urban forestry volunteers and effective outreach. 436-441. Proceedings from Society of American Foresters National Convention. Indianapolis.

Wolf, K.L. (2004). Economics and public value of urban forests. *Urban Agriculture Magazine, 13*, 31-33.

Xiao, Q., & McPherson, E.G. (2002). Rainfall interception by Santa Monica's municipal urban forest. *Urban Ecosystems, 6*, 291-302.

Yang, J., McBride, J., Zhou, J., & Sun, Z. (2005). The urban forest in Beijing and its role in air pollution reduction. *Urban Forestry & Urban Greening 3*, 65-78.

Appendix A: Condition rating criteria

Condition Rating Criteria

Condition ratings are assessed in teams of two or three volunteers. Each individual should evaluate the tree independently. Then team members should discuss their ratings. If the condition rating differs greatly between team members, discuss the merit/fault of each rating to resolve the differences.

Each tree will have two separate condition ratings: **Crown Assessment** and **Stem Assessment**. Numeric values for a tree's crown and stem are not averaged. Both are rated on a zero to four point scale. Each tree starts with 4 points from the Crown and 4 points from the Stem. The points recorded on the inventory sheet are deductions in quarter point increments. While in the field, record only the deductions from each section, the total deductions will be done automatically when the data is entered into the computer. Foliage (leaves) are not evaluated in this system.

Crown Assessment

The crown includes everything from the first set of major branches to the top of the tree.

Stag Heading

A condition where an entire main branch is dead from the tip all the way back to the main stem or another major branch. **Up to 1 point** may be deducted based on the size of the dead branch and the percentage of the crown affected.

Figure 1. Stag heading

Tip Die Back

A condition where there is significant death at the tips of branches. Only the outer branch tips are affected. **Up to 0.5 point** can be deducted as a result of this condition.

Figure 2. Tip Die Back in the crown

Symmetry

This condition factor addresses of crown symmetry. Compared to a perfectly symmetrical crown, **up to 1 point** can be deducted if a portion of the crown is missing.

Figure 3. An asymmetrical crown

Live Crown Ratio (LCR)

LCR is a measure of the total photosynthetic potential of a tree. LCR is the ratio of the height of the crown to the total height of the tree. **Remember the crown does not necessarily begin where foliage begins on the tree; the crown starts at where the first main branch(s) attach to the trunk and goes to the top of the tree**. To get a reading of the LCR, hold a tape measure (or ruler) at arm's length standing far enough from the tree to view the entire tree between 0 and 10 inches on the tape. Line up the top of the tree with 0 and the base of the tree with 10 on tape (Figure 4). Standards for LCR with **NO deductions are 60% for deciduous and 75% for coniferous**. As a general rule, deciduous trees with less than 25% LCR should lose 2 points, LCR of 33% would lose 1 point, and 50% LCR could lose up to 0.5 point.

Example: If the top of the tree is at 0" and the bottom of the crown is at 6", then the tree would have a 60% Live Crown Ratio and no deductions would be recorded.

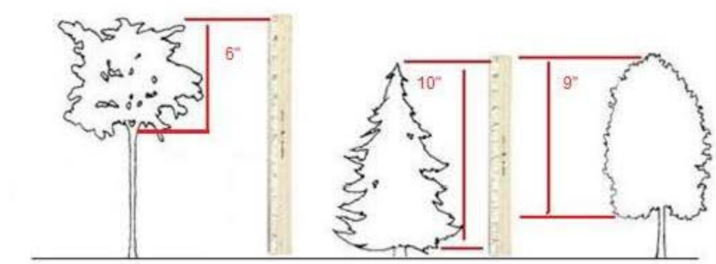


Figure 4. Live Crown Ratio: Standing far from the tree, line up your ruler or tape measure with the height of the tree. Find the height of the crown, and express it as a percentage of total height. The trees above would have LCR's of 60% (6 inches ÷10 inches),

Stem Condition

The stem (or trunk) is the portion of the tree from the ground line up to the first set of major branches.

Cambium Loss

Cambium is living tissue that creates the systems for moving water and nutrients throughout the tree. Generally, there has been cambium loss where there is missing or loose bark. Points are deducted for any loss of cambium due to pruning wounds, accidental damage, vandalism, and winter injury. **Up to 3 points can be deducted if 50% or more** of the stem's circumference is girdled. Use this recommendation to calculate lower rates of girdling (**e.g. a tree that is missing 25% of its cambium would have a 1.5 point deduction**). Don't add vertical cambial loss, only add up circumferential loss.

Figure 5. Cambium loss

Decayed Wood

Decayed wood requires a **deduction of 0.25 point minimum** or more if it shows obvious signs of decay (i.e. "punky" or soft wood). Points should be deducted based on the significance, location and amount. There is no maximum point deduction; however, any point deduction of 4 points or more will result in a final stem condition rating equal to zero (the worse possible score).

Figure 6. Exposed and decayed wood

Sprouts/Suckers

Deduct up to 0.5 point for excessive sprouts or suckers. Sprouts can also be referred to as water sprouts and are excess growth off the main stem of the tree. Suckers are growth located at or around the base of the tree.

Figure 7. Sprouts and suckers

Stem Cracks

Depending on the severity, **up to 2 points can be deducted** for stem cracks. Severity increases with multiple cracks, size and extent of the crack.

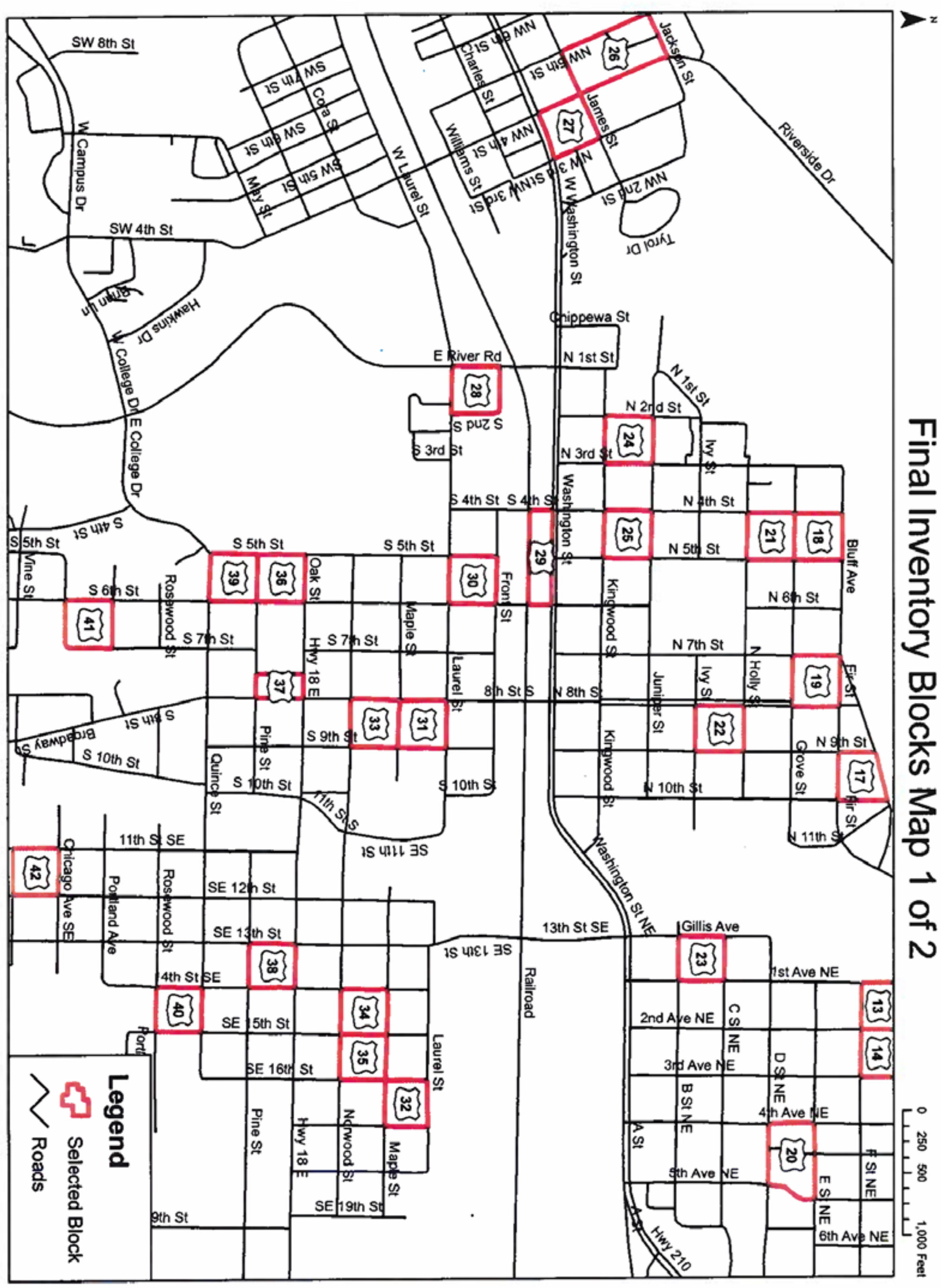
Figure 8. Stem crack

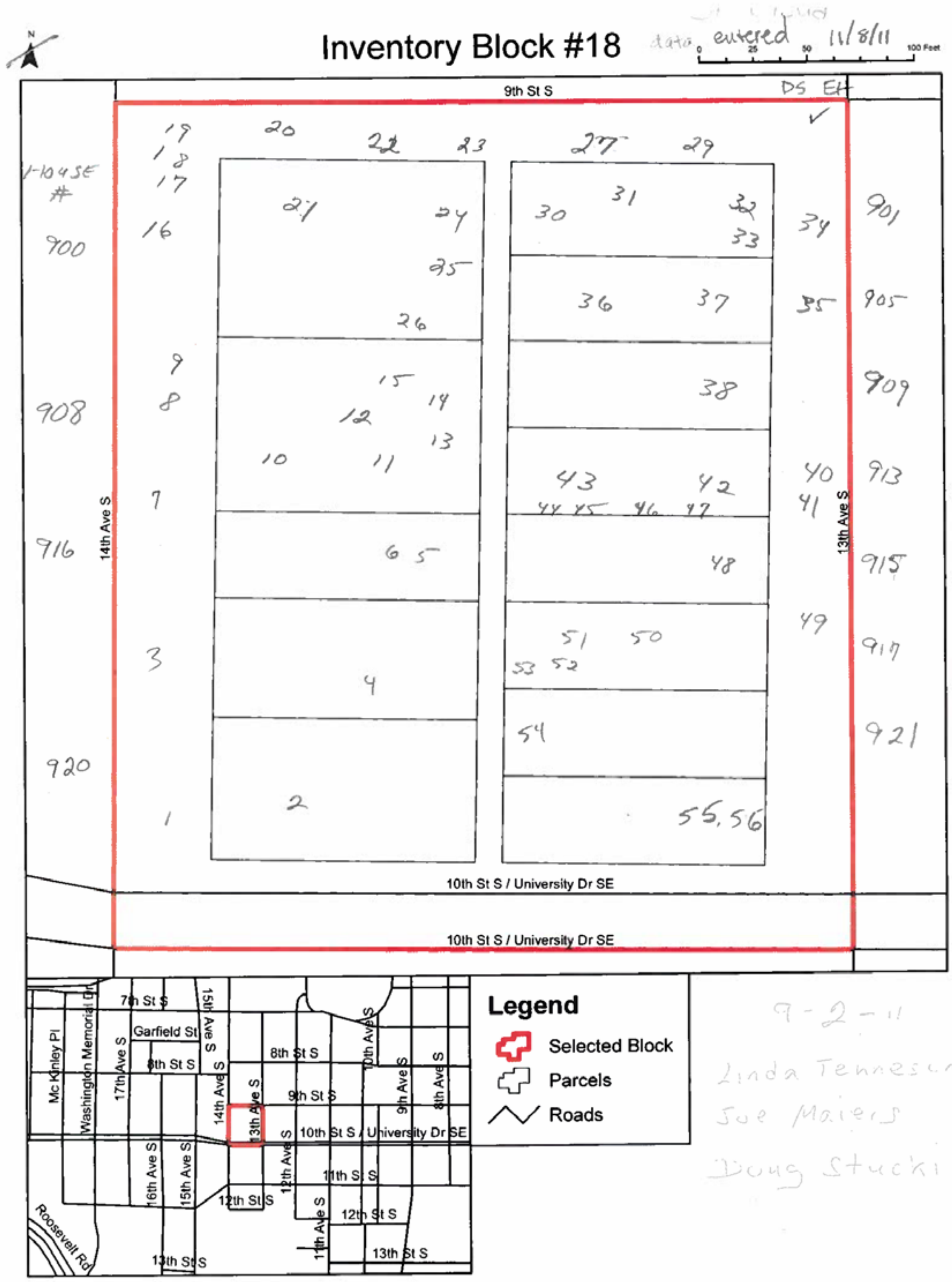
Included Branch Unions

Point deduction is a function of the number and severity of inclusions. **A maximum of 0.5 point can be deducted**. Only the first main branches can be considered when deducting points for this category. Anything further up in the crown of the tree is **NOT** considered for stem condition rating.

Figure 9. Included branch unions

Appendix B: Block Map and data sheet




Inventory Block #18
data entered 11/8/11
0 25 50 100 Feet
N
9th St S
DS EH
14th Ave S
13th Ave S
10th St S / University Dr SE
10th St S / University Dr SE
1-104 SE #
900
908
916
920
901
905
909
913
915
917
921
Legend
Selected Block
Parcels
Roads
9-2-11
Linda Tennesen
Sue Maiers
Doug Stucki

Community Name:

Group Member Names:

Date:

Zone:

							PUBLIC TREES ONLY										
							Crown Assessment				Stem Assessment						
General Information				Tree Information			Stag Heading	Tip Die Back	Symmetry	Live Crown Ratio	Cambium Loss	Exposed or Decayed Wood	Sprout/ Sucker	Stem Cracks	Included Branch Unions	Defects	Comments/ Notes
Block #	Tree #	Res	Pub	Species	DBH (nearest inch)	Crown Width (nearest foot)	Up to 1 pt	Up to 0.5 pt	Up to 1 pt	25% or less - 2 pts 33% or less - 1 pt 50% or less - 0.5 pt	Up to 3 pts	Minimum 0.25 pt	Up to 0.5 pt	Up to 2 pts	Up to 0.5 pt	Defect code below	